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ANALYSIS OF A1 DIFFUSION IN MOLTEN GERMANIUM INDUCED BY PULSED Nd:YAG LASER USING SIMS TECHNIQUE

RAID A. ISMAIL and ALI M. MOUSSA
School of Applied Sciences, University of Technology, Baghdad, Iraq.

دراسة تحليلية للانتشار المحتث بالليزر النبضي لشوائب الالومنيوم في منصهر الجرمانيوم باستخدام تقنية المطياف الكتلي للايونات الثانوية

رائد عبد الوهاب إسماعيل و علي مطشر موسى
الجامعة التكنولوجية / قسم العلوم التطبيقية
بغداد / العراق

في هذه الدراسة تم قياس معامل وشكل انتشار شوائب الألومنيوم في منصهر الجرمانيوم باستخدام تقنية المطياف الكتلي للايونات الثانوية، حيث تم استخدام ليزر النديميوم – ياك النبضي في عملية الانتشار المحتث . من الحسابات ظهر أن معامل الانتشار وهيئة توزيع شوائب الألومنيوم في الجرمانيوم تعتمد بشكل كبير على كثافة طاقة نبضة الليزر، وقد أوضحت النتائج أن مقدار معامل الانتشار تراوح مابين ٦,٦٩ × ١٠$^{-٩}$ – ٨ و ٥ × ١٠$^{-٨}$ سم^{٢} / ث .

Key words: Diffusion coefficient, SIMS, Nd:YAG laser, segregation coefficient.

ABSTRACT

In this work the volume diffusion coefficients and profile distribution of A1 impurities in molten germanium have been measured using secondary-iron mass spectroscopy (SIMS) technique. Diffusion is achieved with aid of Nd:Yag laser pulses. In this study it is shown that the diffusion coefficients and profile distribution of impurities are extremely sensitive to laser energy density. The calculated diffusion coefficients are ranging from 6.69 x 10^{-9} to 5.9 x 10^{-9} $cm^2.s^{-1}$.

INTRODUCTION

Single step laser-induced diffusion in semiconductors is an attractive method to fabricate high quality p-n junctions [1-3]. In our preliminary experiments we have investigated structural and electrical characteristics of germanium doped with various dopants by means of pulsed Nd:Yag laser [4-7].

Secondary-iron mass spectroscopy is an available analytic tool for quantitative measurements of the impurity diffusion characteristics [8-12]. Droner et al used the secondary-iron mass spectroscopy (SIMS) to measure the solid phase diffusion coefficients of Al impurities in germanium crystals [13]. Since the dopants profile distribution and the diffusion coefficient are very important parameters in fabrication of semiconductor devices, we focused attention to determine the volume diffusion coefficients of Al impurities diffused in molten germanium using SIMS technique.

EXPERIMENT

The starting material in our study was n-type (311) oriented single crystal germanium with electrical resistivity of 45 Ω.cm. 500 μm thickness. The surface preparation consisted of mechanical polishing with (Al_2O_3) powder of decreasing grain size (5, 3, 1 and 0.5 μm) on microcloth until a mirror-smooth surface evolved. For each step, the Ge sample is dipped into solution of $Al_2(SO_4)_3$ with about $1.2x10^{21}$ cm^{-3} atoms of aluminium. The experimental setup used is shown in Fig. (1).

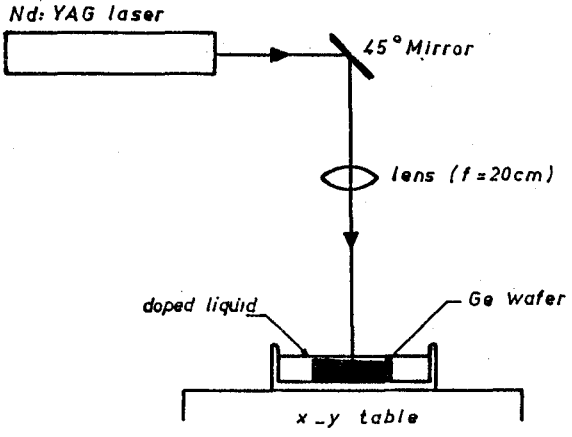


Fig. 1: Schematic drawing of experimental set-up

Irradiations are performed at room temperature by using single laser pulse under conditions listed in table (1). The thickness of liquid dopant layer covering the Ge sample was 1 mm typically, and spectral transmission of the solution to the wavelength 1.064 μm is taken into consideration. The profile distribution of Al impurities in Ge after laser irradiation was performed by in-depth perpendicular to the surface with a Cameca IM-30 secondary-ion mass spectrometer. A low energy of Ar^+ primary ions were used for the present measurements. The intensity of the masses of interest can be recorded as a function of time, so that depth profile can be obtained by using Tally Step (Tencor 100).

Table 1

Laser doping parameters

Wavelength	1.064 μm
Pulse duration	300 μs
Mode	$TEM_{..}$
Pulse energy density	10.33-15 J/cm^2
Beam diameter (1/e^2 points)	1.6 mm

RESULTS AND DISCUSSION

Fig. (2-a) shows the profile distribution of Al impurities in germanium doped with laser energy density 10.33 J/cm^2.

The impurity-ion signal (≈ concentration) was maximum in the vicinity of the surface, and then decreased smoothly up to diffusion depth ≈ 65 nm. This effect can be attributed to segregation during solidification, the segregation coefficient of Al impurity in germanium is less than unity [14]. The segregation coefficient can be defined by [15].

$$K = \frac{C_s}{C_l} \qquad (1)$$

where

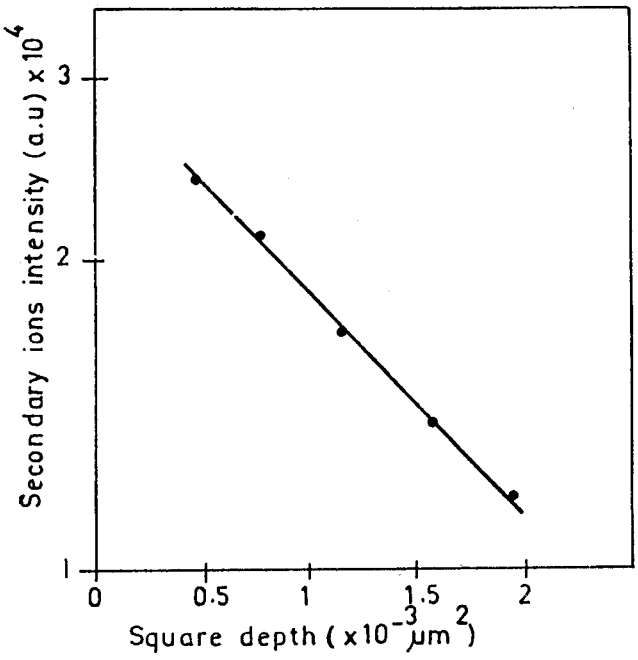
C_s : Concentration of impurities in solid phase
C_l Concentration of impurities in liquid phase

When a laser beam with sufficient energy density strikes the Ge sample, melting takes place and the Al impurities diffuse to a certain depth. When the solidification process occurs the melted front returns toward the surface and some atoms remain in the solidified layer, while (1-K) C_l atoms are to be rejected from the formed solid into adjacent molten layer. This means that the impurities will move towards the sample surface. According to the described interface kinetics, the impurities having an interfacial distribution coefficient (segregation coefficient: K<1) should accumulate at the surface, i.e. an enriched layer (p^+) of Al forms in the liquid at the interface. The amount of dopants accumulated at the surface should also increase with decreasing K.

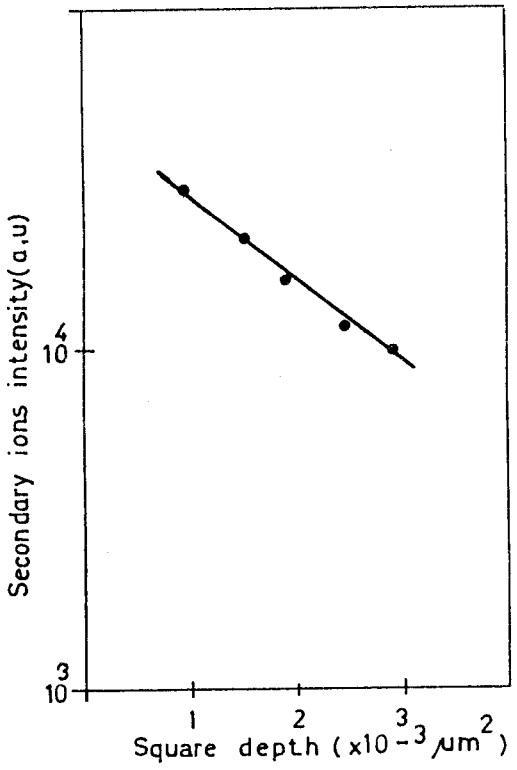
Fig. (2-b) illustrates the profile distribution of Al dopants in Ge crystal doped with 11.54 J/cm^2. It is clear that the accumulation of Al impurities at the surface is more pronounced, and then more depleted at depth ≈ 63 nm. A significant amount of out-diffusion occurs when the energy density increases. When the laser energy density is increased to 13 J/cm^2 the melting depth is increased, and Al atoms have a sufficient time to diffuse deeper into bulk germanium and as a result the diffusion depth is increased to about 0.24 μm as shown in Fig. (2-c). Compared with the profile of Al impurities at 13 J/cm^2 the depth profile distribution exhibits an increasing broadening at 15 J/cm^2 as illustrated in Fig. (2-d).

It appears that pronounced modification is introduced in the Al impurities profile distribution. The diffusion depth was more than two times higher than that of the 13 J/cm^2. On the other hand, the accumulation of Al at the surface is more pronounced.

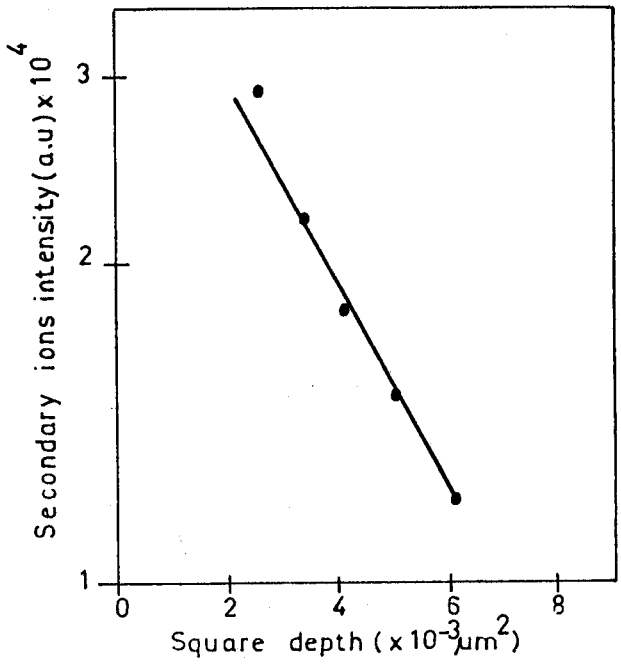
Fig. (3) shows the impurity signal intensity (I) plotted logarithmically versus the square of diffusion depth (Z^2) and the slope of the straight line can be used to calculate the diffusion coefficient (D) through the relation [13].



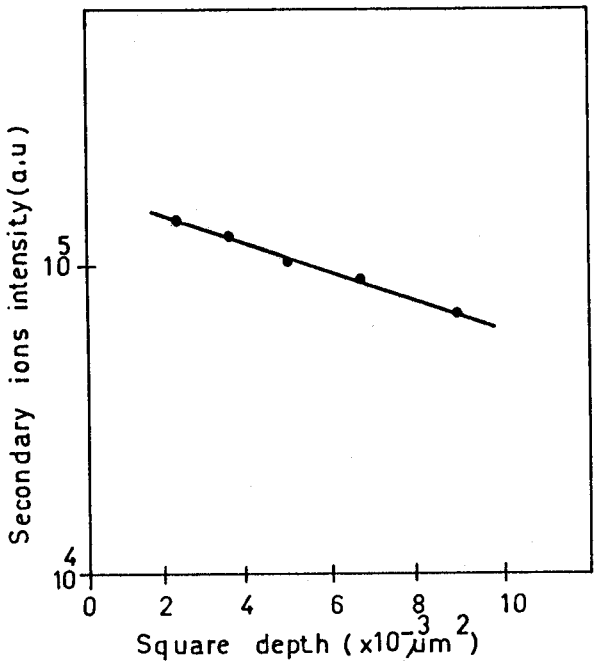
(a)



(c)



(b)



(d)

Fig. (3): A semi-logarithmic plot of secondary ion intensity versus square diffusion depth
(a) 10.33 J/cm^2 (b) 11.54 J/cm^2
(c) 13 J/cm^2 (d) 15 J/cm^2

$$D = -\frac{1}{4t\left(\frac{\text{olin I}}{oZ^2}\right)} \qquad (2)$$

where: t is the diffusion time.

The calculated values of diffusion coefficient of Al impurities diffused in Ge with various laser energy densities are listed in table (2). It is obvious that the diffusion coefficient is increased with increasing energy density of doping. This may be attributed to the decrease of the diffusion

Table 2
Calculated diffusion coefficients for various energy densities

Energy density (J/cm^2)	$D(cm^2.^{-1})$
10.35	6.6×10^{-9}
11.59	7×10^{-9}
13	2.5×10^{-8}
15	5.9×10^{-8}

duration of impurities. The values of the diffusion coefficients are four to eight orders of magnitude larger than those obtained by Droner et al. This constitutes a proof that the liquid phase diffusion is occurred [16].

CONCLUSIONS

The final outcome of the present investigation may be best summarized as follows:

1. The Al impurities accumulated at the vicinity of the germanium surface create a p+ layer.

2. The concentration and the diffusion depth of Al impurities in germanium are very sensitive to laser energy density.

3. Pronounced modification is introduced, in the profile distribution of Al impurities, with increasing energy density up to 15 J/cm^2.

4. Diffusion coefficients of Al impurities increased with increasing laser fluence.

5. Diffusion coefficients of Al impurities are up to four to eight orders of magnitude larger in liquid germanium than in its solid phase.

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